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YUCCA MOUNTAIN – REQUEST FOR ADDITIONAL INFORMATION (RAI) –VOLUME 2, CHAPTER 2.1.1.1 SECOND SET (DEPARTMENT OF ENERGY'S SAFETY ANALYSIS REPORT SECTIONS 1.1.4, 1.1.5, and 1.3.4) – Site Description

Reference: Ltr, Jacobs to Williams, dtd 12/22/08, "Yucca Mountain - Request for Additional Information – Volume 2, Chapter 2.1.1.1 Second Set (Department of Energy's Safety Analysis Report Sections 1.1.4, 1.1.5, and 1.3.4)"

The purpose of this letter is to transmit the U.S. Department of Energy's (DOE) supplemental response to RAI number 3, identified in the above-referenced letter. The original DOE response to RAI number 3 was provided on February 4, 2009. Supplemental response to RAI number 3 is provided as a separate enclosure. The response is based on DOE's understanding of the technical areas requiring further clarification, as discussed in an August 4, 2009, public teleconference. Two DOE documents cited in the response, which has not been previously provided to the U.S. Nuclear Regulatory Commission, are also enclosed.

There are no commitments in the enclosed supplemental RAI response. If you have any questions regarding this letter, please contact me at (202) 586-9620, or by email to jeff.williams@rw.doe.gov.

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OTM:SAB-1059

Enclosures (3):

1. Supplemental Response to RAI Volume 2, Chapter 2.1.1.1, Set 2, Number 3
2. DOE 2008. *High-Level Radioactive Waste and U.S. Department of Energy and Naval Spent Nuclear Fuel to the Civilian Radioactive Waste Management System.* Volume 1 of *Integrated Interface Control Document*. DOE/RW-0511, Rev. 4.
3. Orrell, S.A. 2007. "Preliminary 2007 Geotechnical Drilling Results from the U.S.G.S for the Waste Handling Buildings and Aging Pad Areas." Letter from S.A. Orrell (SNL) to R.J. Tosetti (BSC), May 29, 2007

<u>EIE Document Components</u>:

001_NRC_Letter_2.2.1.1.1_Set_2_Suppl.pdf	
002_Encl_Supp_3_2.2.1.1.1_Set_2.pdf	3,487 kB
003_DOE_RW-0511.pdf	7,630 kB
004_LLR.20070531.0001.pdf	4,245 kB

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RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3:

On August 4, 2009, the DOE participated in a clarification call with the NRC regarding RAI 2.2.1.1.1-2-003. Three areas requiring clarification were identified as follows:

Question 1. Standoff Distances from Faults

a. **RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Section 1.4.1, Page 9 of 13:** Clarify the criteria and technical bases to select a 60 m standoff distance from an emplacement drift waste package end point coordinate (WPEC) to a Quaternary fault of significant displacement such as the Solitario Canyon Fault.

b. **RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Section 1.4.2, Paragraph 1 and 2, Page 9 of 13:** Clarify and quantify the significant displacement and the "standoff distance of a few meters" of other faults that would be encountered during the excavation of a drift or structures, systems, and components (SSCs) that are either important to safety (ITS) or important to waste isolation (ITWI).

c. **RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Section 1.4.1, Page 9 of 13:** Clarify the criteria and their technical bases to select a standoff distance to significant displacement (e.g., Bow Ridge Fault or other faults at the surface GROA). As an example, clarify the technical bases to relocate aging pads 17P and 17R to about 300 feet east of the reinterpreted location of the Bow Ridge fault (Orrell 2007).

d. **RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Section 1.4.2, Paragraph 2, Page 9 of 13; ibid Section 1.4.2, Paragraph 2, Page 9 of 13; ibid, Figures on pages 13 of 13:** Clarify by explaining the technical basis for why the standoff distance is measured from the centerline (plane) of some fault zones and from the outer edge of the other fault zones.

e. **RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Figures on Page 13 of 13:** Clarify how the standoff distances from fault and fault zones to the edges of an emplacement drift or to ITS and ITWI surface facilities are calculated to ensure that the shortest standoff distance is calculated in the context of the three-dimensional setting and not just in a simplified two-dimensional setting.

Question 2. Fault Damage Zone

a. **RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Section 1.2.3, Paragraph 2, Line 5, Page 6 of 13:** Clarify the definition and criteria of a fault damage zone and of a fault zone of influence for the purposes of standoff and clarify and quantify the criteria of narrow and wide fault damage zones.

b. **RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Section 1.2.3, Paragraph 3, Page 6 of 13:** Clarify whether or not future subsequent significant displacement of a fault might occur anywhere in the existing damage zone, including the edge, thereby widening the damage zone of influence.

c. **RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Section 1.2.3.1, Paragraphs 2 and 3, Page 7 of 13:** Clarify how faults encountered during construction with displacements of 2 m or less and with narrow damage zones would not have credible potential effect on the performance of ITS SSCs.

Question 3. Plans for Future Assessments of Faults

a. **In the response to RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Section 1.4.1, Paragraph 4, Page 9 of 13:** Clarify how the location of the Solitario Canyon Fault will be confirmed by near horizontal drilling during initial construction activities and explain how the DOE plans to ensure that this confirmation activity will be performed.

b. **In the response to RAI Volume 2, Chapter 2.1.1.1, Second Set, Number 3, Section 1.4.2, Paragraph 2 Page 10 of 13; Section 1.1.2, Paragraph 4, Page 4 of 13 and SAR Section 1.9, PSC-25, Page 1.9-146:** Clarify how the location, width, and edge of displacement of damage zone of the Bow Ridge Fault; interpreted buried faults; and potential unknown faults in the Midway Valley and in the subsurface GROA will be further assessed for their potential hazards to ITS and ITWI surface facilities during initial construction activities and clarify where the future operational procedures will address the measurement in more detail.

1. RESPONSE

A response to each of the questions is provided in the following sections, with each topic addressed under a separate subsection for clarity.

1.1 QUESTION 1: STANDOFF DISTANCES FROM FAULTS

Various standoffs are implemented between specific design features and certain components of the natural barriers to satisfy the bases of the preclosure and postclosure safety analyses. The standoff distance from a fault and how it is measured varies depending on the Project requirements, the hazard considered, the fault characteristics, and the location of the structure or component (e.g., in the subsurface or surface).

1.1.1 Question 1. Part a: The 60 m Standoff Distance from a Quaternary Fault with Potential for Significant Displacement

SAR Table 1.9-9, design control parameter 01-05 requires that emplacement drifts be located a minimum of 60 m (197 ft) from a Quaternary fault with potential for significant displacement. There are two Quaternary faults with potential for significant displacement in the immediate vicinity of the subsurface geologic repository operations area (GROA): the Solitario Canyon Fault and the Bow Ridge Fault (SAR Section 1.3.4.2.2). A 60 m standoff for the emplacement drifts has been implemented from the expected subsurface locations of these two faults in the design of the GROA. No other Quaternary faults with potential for significant displacement are identified or anticipated to be within the subsurface GROA based on available geologic data.

The 60 m standoff distance determination is based, in part, on a fault displacement analysis (as described in the original RAI response), which shows that induced rock stress and rock mass displacements decrease significantly at this standoff distance. The 60 m value, however, is not based on any specific determination of allowable rock stress or rock mass movement; rather, it is a distance deemed sufficient to achieve postclosure goals. The standoff distance considers the uncertainty in the location of the fault at depth and the extent of the fault damage zone (defined in Section 1.2.1 of this response) in the proximity of the Solitario Canyon and Bow Ridge Faults, as described in SAR Section 1.3.4.2.2. Postclosure seismic hazard evaluations also accounted for potential displacement of the fault (as a block-bounding fault) in considering this standoff distance. For postclosure evaluations, adherence to this design requirement ensures that subsurface facilities are not damaged by fault displacement and reduces the potential for Engineered Barrier System components to experience movement (due to the fault rupture) at a level that potentially could affect repository performance. For the total system performance assessment, the 60 m standoff from the main fault trace is adequate to ensure that the fault does not intersect an emplacement drift and that fault rupture does not have an adverse effect on performance (e.g., SNL 2008a, p. 6-91).

In implementing design control parameter 01-05, the closest approach of the trace of a Quaternary fault with potential for significant displacement to any underground opening in the subsurface GROA (including access mains) exceeds 60 m (197 ft) based on the layout design (BSC 2003, Section 7.1.3). As the waste emplacement is typically located an additional 60 m (197 ft) to the interior away from the access mains, as measured perpendicular to the access main (and away from the Solitario Canyon and Bow Ridge Faults) (e.g., see SAR Figure 1.3.3-34), the design provides a total minimum separation of at least 120 m (395 ft) from a waste package endpoint coordinate (WPEC) to the Solitario Canyon Fault trace.

1.1.2 Question 1. Part b: The Standoff Distance from Other Faults in the Subsurface Geologic Repository Operations Area

For preclosure safety, a preclosure procedural safety control (i.e., PSC-25 in SAR Table 1.9-10) requires that faults encountered during excavation of emplacement drifts in the subsurface facility be specifically evaluated to ensure that conditions cannot credibly lead to a breach of a waste package during the preclosure period or that a standoff distance from the fault is to be established. It is recognized that there is a potential for encountering buried and unknown minor faults in the subsurface, which may or may not pose a credible hazard for preclosure safety depending on the specific characteristics of such faults. Significant displacement from a future earthquake for such faults is defined as the minimum amount of additional (future) offset that could potentially initiate a breach of a waste package.

As discussed in the original response to RAI 2.2.1.1.1-2-003, a fault rupture hazard as related to PSC-25 was examined for the potential breach of a waste package. The potential for damage to a waste package was examined for the special case where the rupture (shear) hazard predominates and where the hazards of potential rockfall or localized dynamic motions are not significant contributors to potentially breaching the waste package. For this case, identified as a narrow fault, a “significant” amount of displacement is deemed to be the minimum future fault displacement necessary for the rock wall to contact a waste package and potentially breach the package due to shearing along the fault. With a horizontal clearance to the rock wall of about 1.5 m (60 in.) on each side of a waste package in an emplacement drift (for a total gap of 3 m at the spring line) and a minimum vertical clearance of the top of the waste package to the tunnel crown of approximately 1.8 m (71 in.), a total displacement of at least 1.8 m (71 in.) (assuming all fault displacement is vertical) must occur before the fault displacement would close this gap and the rock contacts the waste package to apply a shearing stress.

In this regard, based on the probabilistic fault displacement hazard analysis for Yucca Mountain (CRWMS M&O 1998) and available geologic data, the potential consequences from narrow faults with minor total offsets (i.e., of 2 m or less) can be screened from further consideration as a hazard to preclosure safety, as justified in the original response to RAI 2.2.1.1.1-2-003. With a displacement hazard of 2 cm at 10^{-6} mean annual frequency of exceedance for this type of fault (SAR Table 2.3.4-55), the event sequence initiated by such displacement is beyond Category 2 and can be screened from further consideration. Hence, there is no need for a standoff distance from such faults as related to PSC-25.

In the case of encountering narrow faults with larger offsets (i.e., greater than 2 m), additional evaluation of the fault is required (i.e., the fault offset in this case may be regarded as significant). Conceptually, where a shear hazard alone predominates due to future displacement of a fault, a standoff of approximately 2 to 3 m (6.6 to 10 ft) (i.e., “a standoff distance of a few meters”) is deemed sufficient to mitigate the potential for a breach of a waste package (e.g., as illustrated in Figure 1). An example of the use of a limited standoff distance is the criterion adopted (for postclosure considerations) for naval waste packages of a 2.5 m (8.2 ft) minimum emplacement standoff distance from any mapped fault that is determined to have a cumulative offset of at least 2 m (6.6 ft) (SAR Section 1.3.1.1; DOE 2008, Section 10.3.2.1).

Based on the understanding of faults expected to be encountered in the emplacement area (e.g., as captured in Geologic Framework Model or as shown in SAR Figure 1.1-61), the fault displacement hazard of faults with offsets greater than 2 m is limited with only approximately several centimeters of future displacement. For example, for identified faults in the GROA having total offsets greater than 2 m, such as the Sundance Fault, Drill Hole Wash Fault, Pagany Wash Fault, and Sever Wash Fault, the fault displacement hazard ranges from 6 to 15 cm at a mean annual probability of exceedance of 10^{-6} (e.g., SAR Table 2.3.4-55). Although these faults have limited displacements, a standoff distance may still be implemented. Conceptually, it is expected that a standoff of approximately 2 to 3 m (6.6 to 10 ft) would be sufficient to address the potential for waste package breach in compliance with PSC-25 when comparable faults are encountered in the subsurface (i.e., faults with displacement hazards on the order of only several centimeters).

However, for purposes of preclosure safety, a defined standoff distance of a waste package from a specific fault in the subsurface GROA will be established only after evaluation of the specific fault. Faults with offsets greater than 2 m are to be specifically evaluated to ensure that conditions cannot credibly lead to a breach of a waste package, or a standoff distance from the fault is to be established in accordance with PSC-25. The specific program for this evaluation will be defined in plans and construction specifications prior to initiation of construction.

For postclosure, no standoff distance requirements are, for the most part, necessary. Postclosure analyses include the potential for fault displacement along unknown faults or splays within the GROA explicitly (e.g., SNL 2007, Figure 6-107), and the effects on the potential for waste package damage are included in the total system performance assessment (e.g., as noted in SAR Section 2.3.4.5.1.2). For one specific case, a standoff requirement of 2.5 m from a fault in the subsurface GROA is identified for naval waste packages, as previously described (SAR Table 1.9-8, footnote d). Therefore, no other fault standoff requirements in the subsurface are identified for ITWI SSCs (excluding the waste package).

1.1.3 Question 1. Part c: Definition of a Standoff Distance from a Fault in the Surface Geologic Repository Operations Area

For ITS structures within the surface GROA, a standoff distance has been established in a specific case to avoid Quaternary faults with potential for significant displacement, in accordance with *Preclosure Seismic Design and Performance Demonstration Methodology for a Geologic Repository at Yucca Mountain Topical Report* (DOE 2007). The standoff in this case is implemented to mitigate the potential effects of the surface rupture of a fault on the aging pads. The closest Quaternary fault with potential for significant displacement to the surface GROA is the Bow Ridge Fault, which is in proximity to the ITS aging pads of the Aging Facility. No other procedural safety control or design control parameter is identified for ITS surface structures that prescribes a standoff distance from a fault. Further, there is no identified fault standoff distance for non-ITS structures in the surface GROA.

A standoff distance for the aging pads from the Bow Ridge Fault is established based on the characteristics of this fault and employs a straightforward rule to define a standoff that allows for some variation in the location of the fault and of the rupture zone at the surface. The aging pads are presently located over 100 m from the fault trace to ensure that the standoff distance is met with sufficient margin. In more detail, the standoff criterion for the ITS aging pads is implemented by defining a 1:1 slope from the location of the fault trace at the bedrock surface projected upward through the local soils to the surface, as shown in Figure 2. The standoff is defined for a normal fault, with the understanding that the fault rupture through the soil will initially trend along the orientation of the expected fault surface and then will curve toward the vertical after some distance. This behavior and uncertainty in location of the fault is reasonably captured by the 1:1 slope defining the standoff. For this criterion, the horizontal standoff distance from either side of the bedrock fault trace is equal to the depth of soil at the location of concern. From an examination of borings in proximity to the fault in the aging pad area, the maximum depth of soil is about 49 m (162 ft) (Table 1). Use of this maximum soil depth with the 1:1 standoff approach results in a 49 m standoff distance from the Bow Ridge Fault bedrock trace at the aging pad location.

For comparison, the fault standoff approach defined by the Utah Geological Survey (Christenson et al. 2003) is computed. A minimum standoff (setback) from a normal fault is established using the following equations (Christenson et al. 2003, pp. 8 to 9) for the upthrown side (footwall):

$$S_1 = U \cdot [2 \cdot D] \qquad \text{(Eq. 1)}$$

and for the downthrown side (hanging wall):

$$S_2 = U \cdot [2 \cdot D + (F / \tan\Theta)] \qquad \text{(Eq. 2)}$$

where S_1 and S_2 are the standoff distances from the surface extension of the fault, U is the criticality factor based on the International Building Code building occupancy class, D is the expected fault displacement per event, F is the maximum depth of footing or subgrade portion of the structure, and Θ is the dip of the fault. These parameters are illustrated in Figure 3.

For the computation of a standoff from the Bow Ridge Fault for the case of the aging pad, U is set equal to 3 for International Building Code occupancy class "High Hazard" (Christenson et al. 2003, Table 1), D is set to 2.4 ft (73 cm) based on the mean fault displacement hazard for the Bow Ridge Fault with a mean annual probability of being exceeded of 10^{-6} (SAR Table 2.2-15), F is set at 4 ft (1.2 m) (the thickness of the pad plus an allowance for the subgrade base) (SAR Section 1.2.7.1.3.1), and Θ is set to 75° (Keefer et al. 2004, Table 5). As shown in Table 2 for these values, the computed standoff values are S_1 = 4.4 m (14 ft) and S_2 = 5.4 m (18 ft). Both of these distances are below the minimum standoff of 15.2 m (50 ft), as identified for this category of structures (Christenson et al. 2003, Table 1). Therefore, the minimum standoff distance from the surface extension of the fault using the Utah Geological Survey approach is 15.2 m (50 ft).

To directly compare the standoff distance for the 1:1 approach to the Utah Geological Survey standoff distances, the distance from the bedrock trace to the surface trace of the fault must first be computed. Taking the surface trace of the fault as the extension of the bedrock fault surface (dip) to the surface, the distance from the surface extension of the fault to the subsurface trace (see Figure 3) can be estimated considering the depth of soil and the fault dip, expressed as:

$$C = H \cdot \text{cotan}(\Theta) \qquad \text{(Eq. 3)}$$

where C is the distance between the subsurface trace and the extension at the surface in the direction of the upthrow, H is the depth of soil, and Θ is the dip of the fault. For a depth of soil of 49 m (162 ft) and Θ equal to 75°, C equals 13.1 m (43 ft). Therefore, the Utah Geological Survey setback distance from the fault trace (at bedrock) to east of the fault is obtained by adding S_1 with the distance *C* to obtain 29 m (15.2 + 13.1 = 29 m [rounded up] or 95 ft). The value of 29 m is well within the 49 m standoff defined earlier for the 1:1 slope.

A comparison can also be made to current regulations, although there is little regulatory guidance in defining setback distance from a fault. It is noted that 40 CFR Part 264, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities*, provides a requirement for the location of hazardous waste treatment, storage, and disposal facilities with regard to recent fault activity. Specifically, as stated in 40 CFR 264.18, facilities for the treatment, storage, or disposal of hazardous waste are not to be located within 61 m (200 ft) of a fault that has displaced in the Holocene Epoch (i.e., within the last 10,000 to 12,000 years). 40 CFR 258.13, *Criteria for Municipal Solid Waste Landfills*, makes a similar requirement for municipal solid waste landfills but allows an alternate setback distance if it can be demonstrated that this alternate distance will prevent damage to the structural integrity of the municipal solid waste landfill facility unit and will be protective of human health and the environment. However, neither 40 CFR Part 264 nor 40 CFR Part 258 are directly applicable to Yucca Mountain.

The minimum horizontal separations in the current design of the aging pads from the along-dip surface projection of the Bow Ridge Fault are identified by distances A and B in Figure 4, and the separation distances are listed in Table 3. The minimum horizontal distance of the aging pad area 17R to the surface trace of the Bow Ridge Fault (i.e., length A) is approximately 101 m (330 ft) as measured in the source figure between the pad edge and the extension of the fault to the surface along the fault dip. Correcting this value to obtain the distance to the vertical projection of the bedrock trace (i.e., by adding the distance, *C*, of 13 m), the minimum distance between the aging pad and the bedrock trace is approximately 114 m (374 ft). Similarly, the minimum distance of the aging pad area 17P to the surface trace of the Bow Ridge Fault (i.e., length B) is approximately 136 m (445 ft), and correcting the distance to location of the bedrock trace, the separation distance is approximately 149 m (489 ft). Therefore, both aging pad areas are beyond the standoff distance defined by the 1:1 slope of 49 m, the setback calculated using the Utah Geological Survey approach of 29 m, and the distance of 61 m noted in 40 CFR 258.13 and 40 CFR 264.18.

It is noted that other (i.e., unnamed) faults are shown in Figure 4 under the aging pads. As these faults show no evidence of displacing Quaternary alluvial deposits based on available geologic evidence, no standoff distance from these faults is required or identified.

1.1.4 Question 1. Part d: Differences in Measuring Standoff Distances

A standoff distance from a fault may or may not include an allowance for the extent of intense fracturing near the fault, based on the purpose of the standoff. Therefore, the method used to measure the standoff distance differs from one application to another.

For the minimum 60 m standoff of an emplacement drift from a Quaternary fault with potential for significant displacement, the standoff value includes the potential uncertainty in the location of the fault as well as consideration of the fault damage zone (i.e., the zone of brecciated rock and gouge of the fault is taken into account in determining the adequacy of the 60 m standoff value) (see Section 1.2.1 of this response). From a postclosure perspective, the purpose of standoff is to avoid the main trace of the fault along which significant displacement may occur during an earthquake. Off-fault, secondary displacements along minor faults and splays are included in the total system performance assessment and, therefore, need not be avoided for this standoff distance. Therefore, it is appropriate to measure a standoff from the main fault trace of the fault. Similarly, for the 49 m standoff distance from the Bow Ridge Fault for surface ITS structures, the approach is sufficient and accommodates the fault damage zone of this fault.

In contrast, to address the requirements of preclosure procedural safety control, PSC-25, the discussion (provided in the original response) was focused on the specific case of a hazard due to a narrow fault where the potential shear of the waste package is the predominant hazard. As faults are often not a single discontinuity in the subsurface, the term “fault damage zone” was used to encompass the entire zone of potential displacement along a fault, and the standoff distance was taken as the minimum distance from the edge of the fault damage zone to the edge of a waste package. A similar measurement approach can be employed for naval waste packages. Future operational procedures will address these measurement considerations for faults encountered in the subsurface in more detail. SAR Section 5.10 identifies that administrative controls within the License Specifications will require that procedures be established, implemented, and maintained to satisfy procedural safety controls, including PSC-25.

1.1.5 Question 1. Part e: The Measurement of the Shortest Standoff Distance

The 60 m standoff distance of emplacement drifts from a Quaternary fault with potential for significant displacement, in accordance with design control parameter 01-05, is measured in a horizontal plane at the emplacement level. For this distance measurement, the edge of any emplaced waste package (i.e., the WPEC) is delineated as the edge of the emplacement area. As a clarification to the original RAI response, the 60 m (197 ft) fault standoff distance is measured in the original layout calculation as the shortest distance from the emplacement drift’s WPEC (located horizontally at the top of rail) to the main fault trace projected to the elevation of the emplacement drift (line O_1 in Figure 5). A more comprehensive method for this measurement has been recently identified and used to confirm the standoff distance (as described in the original response to RAI 2.2.1.1.1-2-003), which involves taking two such distance measurements: one at the plane of the emplacement drift invert (base of excavation) elevation and a second measurement at the plane of the emplacement drift crown, with the shorter of the two distances used for compliance confirmation (i.e., the shorter of the two lines A_1 and A_2 in Figure 5). A revised figure showing both these methods is attached (Figure 5). As the orientation of both the Solitario Canyon and the Bow Ridge Faults (i.e., the strike) is approximately parallel to the edge of the subsurface GROA, the latter method accounts for fault dip and thereby provides a minimum distance with sufficient accuracy for the postclosure requirement and is planned to be used for operations. Further, significant margin exists for the standoff requirement for the closest approach of this type of fault to the emplacement area. The Solitario Canyon Fault, which has the closest approach to Panel 4, as described in Section 1.1, provides a total minimum separation of the waste package endpoint from the Solitario Canyon Fault trace of at least 120 m (395 ft).

The standoff distance of the aging pad from the Bow Ridge Fault is measured as described in Section 1.3 of this response. The standoff distance is taken from the trace of the fault at the top of bedrock, which is projected vertically to the surface. The standoff distance is measured horizontally at the surface from the fault trace projection to the edge of the aging pad. The distance measured is the shortest distance between two lines in a horizontal plane and is appropriate to the process of defining this standoff distance. Tables 2 and 3 of this response allow for a comparison of the significant margin of this standoff requirement from the aging pads to the closest approach of the Bow Ridge Fault.

To address the preclosure safety requirement of PSC-25 for faults in the subsurface, the standoff is measured as the shortest geometric distance from the fault damage zone (defined in Section 1.2.1 of this response) or its projection to a point on any adjacent waste package. Figure 2 of the original response depicts the standoff distance in an emplacement drift for a simple case and was intended for illustrative purposes only and not to provide a definitive methodology for measurement. The figure was also not meant to suggest a simple two-dimensional measurement along the tunnel axis.

To ensure that the shortest standoff distance is calculated in this case, the measurement of the standoff distance can be accomplished in three-dimensional space using plane geometry by representing the edge of the fault damage zone as a plane (e.g., measured in terms of strike and dip from the surface in the emplacement drift), as illustrated in Figure 1. Computing the normal to the plane using a three-dimensional coordinate system and identifying the closest point on the waste package planned for emplacement near the fault, the minimum distance can be computed between a fault plane defined as $ax + by + cz + d = 0$ and a point $p = (x_1, y_1, z_1)$ using the following equation:

$$D = \frac{|ax_1 + by_1 + cz_1 + d|}{\sqrt{a^2 + b^2 + c^2}} \qquad \text{(Eq. 4)}$$

where D is the minimum distance between an identified point on the waste package and the fault. To compute the absolute shortest distance (i.e., the global minimum) as a basis for the standoff distance, it may be necessary to examine several points on the waste package. This computation process can be automated in a simple computer code or calculated by hand for several points on the waste package until the global minimum is identified as a basis for the subject standoff criterion. The actual process will be described in future operational procedures.

A similar method may also be used to measure the standoff requirement adopted for postclosure considerations for naval waste packages, that is, a standoff distance of 2.5 m (8.2 ft) from a waste package to any mapped fault.

1.2 QUESTION 2: FAULT DAMAGE ZONE

1.2.1 Question 2. Part a: Definition of a Fault Damage Zone Versus a Fault Zone of Influence and Definition of Narrow Fault Damage Zone

For the determination of a standoff distance, a "fault zone of influence" is not identical to a "fault damage zone." A fault zone of influence is a zone around the principal fault plane in which fracture intensity (defined as the number of fractures per unit of length) is higher than in the surrounding rock or in which some other parameter (such as fracture orientation) changes in response to the presence of the fault, as described in the license application (SAR Section 1.1.5.1.3.2). This is illustrated in Figure 6. As related to preclosure safety methodology, a fault damage zone is a zone adjacent to a fault where the hazard of rockfall or fault rupture (which can potentially breach the waste package) is significantly increased from the hazard identified for the overall rock mass around an emplacement drift (the rockfall hazard is addressed in preclosure safety for typical emplacement drift conditions with a bounding approach in which a large rock block controlled by local jointing is considered).

A "fault zone" is typically used to describe the zone of intense fracturing (i.e., very closely spaced fracturing) with breccia and/or gouge. However, in SAR Section 1.1.5.1.3.2 and elsewhere in the license application, the term "fault zone" is used more broadly, and includes a zone of influence. Therefore, a fault zone in the context of the SAR is larger than the zone of primary fault displacement and associated intense fracturing (as illustrated in Figure 6). Mechanistically, the term "fault zone" as used in the SAR includes parameter changes (such as changes in fracture intensity or orientation) in the rock mass associated with the original formation of the fault, as well as subsequent deformation due to successive fault displacement. It is noted, however, that once a fault exists, subsequent deformation (and the impact on the surrounding rock mass) can be more limited than the original formation disturbance, depending on the characteristics of the fault. Therefore, displacement of an existing fault is expected to be restricted to a much more narrow zone than that defined by the "zone of influence," which encompasses the total changes to the rock mass due to fault creation and subsequent displacements.

For the purposes of describing the preclosure safety hazard, the term "fault damage zone" is introduced in this response, distinct from a "fault zone of influence" or a "fault zone" (Figure 6). A fault damage zone is defined as a zone of faulting that can represent a potential hazard for breaching a waste package. The extent of a fault damage zone includes zones of intense fracturing with breccia or gouge between the surfaces of the fault as well as zones of intense fracturing (i.e., zones of closely spaced fractures) directly associated with a fault. However, the term does not include zones of rock that are largely intact with some minor additional fractures or minor changes in properties. The definition also does not spatially combine fractures or zones that are widely spaced.

The definition of the width (i.e., narrow versus wide) of a fault damage zone is used only in regard to the potential preclosure hazard to a waste package. A narrow fault damage zone is defined as a zone where shear displacement alone is the predominant hazard, and therefore, by definition, it is limited in extent and does not pose a significant additional rockfall hazard to the waste package. A wide fault damage zone could potentially contain larger rock blocks than accounted for in the key block analysis used to assess rockfall hazard for the preclosure period, which may pose a credible rockfall hazard for preclosure safety and may require specific evaluations.

Based on the stated hazard, it is possible to establish the criteria for narrow and wide fault damage zones for the purposes of preclosure safety analyses. A width of a fault damage zone of approximately 10 to 30 cm may be conceptually defined as narrow, as any rockfall from such a zone would produce minor rock blocks and chips, with no credible potential for breach of a waste package from a rock impact. Wider fault damage zones, characterized by larger rock blocks and rockfall (used as the limiting basis of analysis in the nonlithophysal units), may pose a credible hazard of waste package breach for preclosure safety. The distinction is therefore quantified as a maximum width of approximately 30 cm for a narrow fault damage zone, while a wide fault damage zone is larger in dimension.

1.2.2 Question 2. Part b: Deformation within a Fault Damage Zone and Widening of the Zone

For purposes of fault standoff with respect to PSC-25, displacement is assumed to be possible anywhere within the "fault damage zone." For zones of intense fracturing filled with breccia and gouge, the displacement hazard of this faulting would be assumed to potentially occur anywhere in the existing fault damage zone, including at the edge.

Subsequent deformation along faults at the site is not expected to appreciably increase the width of fault damage zones with respect to PSC-25. As noted in Section 1.2.1 of this response, future deformation of faults near the GROA is expected to be focused within narrow zones along the main fault trace, as evidenced by gouge and breccia (the fault damage zone). Conceptually, substantial additional displacement on a normal fault, in the range of tens of meters, may widen the zones of breccia somewhat along this fault due to kinematics of the rock mass. However, for a future fault displacement of up to 10 to 20 cm (SAR Table 2.3.4-55; Sites 3, 4, 5, 7, and 8) that can potentially occur during the next 100 years (i.e., the preclosure period), an increase in width of the fault damage zone of more than a few centimeters is not likely (i.e., Beyond Category 2) and would not be included directly in defining standoff distances with respect to PSC-25. In addition, as fault displacement is focused along the fault damage zone, there is no expectation of an increase in the width of a fault zone of influence.

Postclosure performance analyses have incorporated adequate uncertainty such that changes in fault characteristics are not expected to the repository postclosure performance requirements.

1.2.3 Question 2. Part c: Potential Hazard of Minor Fault Displacements

As stated in the original RAI response, the potential for displacement along a narrow fault (i.e., a fault with an observed total offset of 2 m (6.6 ft) or less) is not a credible hazard for preclosure safety (i.e., the potential for breach of a waste package). This type of fault does not require additional evaluations, as stated in PSC-25. The following observations support this conclusion:

- The probability of exceedance for displacement along this fault is very small to negligible. At a mean annual probability of exceedance of 10^{-6}, this type of fault has a displacement hazard of only about 2 cm. This value is insufficient to close the approximately 1.8 to 3 m (vertical/horizontal) gap between an emplaced waste package and the emplacement drift wall and, hence, is insufficient to initiate any shearing action on the waste package. The event sequence that can be initiated by this amount of fault displacement is, therefore, Beyond Category 2.

- By definition, the width of the fault damage zone is narrow (narrow is discussed in Section 1.2.1 of this response), and the potential for producing any rock blocks of substantial size from this zone that can breach a waste package is not credible. Further, given the potential for only limited displacement along the fault, the rockfall in other parts of the emplacement drift induced by the limited fault displacement on this fault is bounded by the maximum potential rockfall hazard identified for preclosure safety caused by a major seismic event (BSC 2007).

- In the analysis presented in the original RAI response, all faults with 2 m or less cumulative displacement were considered as a potential hazard regardless of the age of the fault. As noted in the original response, it was acknowledged that the dating of faults in the subsurface would be problematic, and therefore, it was conservatively assumed that, for this specific case, any fault could pose a hazard.

- For this type of fault, the displacement hazard for the design basis fault displacement category 2 (DBFD-2) is considered negligible. At DBFD-2, described in *Preclosure Seismic Design and Performance Demonstration Methodology for a Geologic Repository at Yucca Mountain Topical Report* (DOE 2007, Sections 5.1 and 5.2), the fault has a future displacement hazard of less than 0.1 cm at a 10^{-5} mean annual probability of exceedance (SAR Table 1.1-67).

- The standoff requirement for PSC-25 is limited to the preclosure safety considerations alone and does not explicitly address postclosure safety aspects, nor does it provide a standoff distance for SSCs other than the waste package.

Therefore, it is concluded that faults encountered during construction with a total offset of 2 m or less and with a narrow damage zone do not have a credible potential for breach of a waste package. Faults with larger offsets encountered during excavation of the emplacement drifts will be evaluated and findings documented in accordance with preclosure procedural safety control, PSC-25.

1.3 QUESTION 3: PLANS FOR FUTURE ASSESSMENTS OF FAULTS

1.3.1 Question 3. Part a: Confirmation of the Location of the Solitario Canyon Fault

As stated in SAR Section 1.3.4.2.2, during initial construction activities in the vicinity of the Solitario Canyon Fault area, the location of the Solitario Canyon Fault will be confirmed and the condition of the rock near the fault will be examined. Specific methods to make such determinations will be identified as part of construction planning, and proven exploratory and mining technologies will be utilized as appropriate. One available method to confirm the fault location is the use of near-horizontal drill holes extending from the access main, into and across the fault to determine its orientation and the extent of the fault structure at a particular location.

For example, the investigation can utilize three drill holes arranged in a triangular configuration, similar to exploration proposed for saturated zone fault hydrology testing of the Solitario Canyon Fault in the *Performance Confirmation Plan* (SNL 2008b, Section 3.3.1.6). As the purpose of the drilling is to confirm the standoff distance, the drill holes would be near-horizontal in orientation and performed at the point where the fault is expected to be closest to the emplacement drifts of the underground GROA. As such, the drill holes are extended from the access main or from a dedicated alcove off the access main along the west side of the repository to the fault, and core evaluations are performed to examine the condition of the rock mass near the fault, as appropriate.

To ensure that the activity will be performed, necessary confirmatory investigations and related requirements, as stated in the SAR, will be incorporated into construction plans and specifications when they are developed, and the results of the evaluations, as appropriate, will be documented. The mapping of faults and determination of standoff distances is part of the Waste Package Loading, Handling and Emplacement Program identified in SAR Table 5.10-3.

1.3.2 Question 3. Part b: Additional Investigations of Faults

As identified in SAR Section 1.3.4.2.2, additional investigations are to be conducted to ensure that the standoff from the Solitario Canyon Fault has been implemented in conformance with the design control parameter 01-05 (SAR Table 1.9-9), as discussed in the previous section. Further, buried or unknown faults in the subsurface GROA are to be addressed in accordance with PSC-25 (SAR Table 1.9-10) and the DOE methodology in *Preclosure Seismic Design and Performance Demonstration Methodology for a Geologic Repository at Yucca Mountain Topical Report* (DOE 2007). In this case, geologic mapping of the subsurface will be performed as part of performance confirmation activities (e.g., SNL 2008b, Section 3.3.2.1; SAR Table 4-1). Upon identification of a fault, the characteristics of the fault will be evaluated, and activities, if deemed necessary, will be conducted to determine the potential of the observed fault to credibly lead to a breach of a waste package during the preclosure period, in accordance with PSC-25.

For the surface GROA, evaluations of the foundation excavations are to be conducted. If buried or unknown faults are identified during such future investigations or foundation construction efforts, additional fault-specific investigations will be conducted, as necessary, to define the hazard in a manner sufficient to implement the preclosure methodology. No additional fault-specific investigations have been identified for the surface GROA area at this time.

Investigations conducted in Midway Valley (e.g., Keefer et al. 2004, p. 27) have not identified any Quaternary fault that underlies an ITS surface facility within the surface GROA. The Midway Valley Fault has been investigated, and the fault is not identified as a credible hazard based on available geologic evidence, including no evidence indicating that the fault displaces Quaternary alluvial deposits (Keefer et al. 2004, p. 27 and Table 5). Therefore, the Midway

Valley Fault is not a Quaternary fault to be addressed by the preclosure methodology (DOE 2007). Additional investigations were conducted in 2006 and 2007 in the surface GROA in the vicinity of the Bow Ridge Fault. Based on these investigations, the Bow Ridge Fault location was revised (Orrell 2007), and the aging pads were relocated to maintain an appropriate standoff distance, as described in Section 1.1.3 of this response. The 2006 and 2007 studies adequately identified the location, width, and edge of displacement of the damage zone of the Bow Ridge Fault. Therefore, no additional studies of the Bow Ridge Fault or other faults in Midway Valley are planned.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

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Table 1. Representative Borings and Soil Depth near Aging Pads

Representative Boring	Soil Depth (m [ft])
UE25 RF#71	49.3 [161.7]
UE25 RF#75	18.4 [60.4]
UE25 RF#76	40.2 [132.0]
UE25 RF#78	41.3 [135.6][a]
UE25 RF#79	40.3 [132.3]
UE25 RF#80	39.0 [127.9]
UE25 RF#97	24.1 [79.1]
UE25 RF#113	38.3 [125.7]
Maximum Soil Depth	49 [162]

NOTE: [a] Soil depth for RF#78 has been recently corrected by 0.1 ft.

Table 2. Standoff Distance Computations

Method	Description	Required Standoff Distance (m [ft])
1	1:1 Slope from Bow Ridge Fault at Bedrock—Based on Maximum Soil Depth	49 [162]
2	Utah Geological Survey Method: S_1 (Upthrown Side) S_2 (Downthrown Side) Minimum Default Setback (High Hazard) C (Difference between bedrock and surface trace) East Standoff from Fault Trace = Minimum + C	 4.4 [14] 5.4 [18] 15.2 [50] 13.1 [43] 29 [95]

NOTE: Method 1 is based on soil depths shown in Table 1.
Method 2 is computed using equations provided in *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson et al. 2003). Value for method 2 is rounded up to the nearest meter.

Table 3. Horizontal Separation Distances from Bow Ridge Fault at Bedrock to Aging Pads

Description	Approximate Distance (m [ft])
Pad 17 R	
1. Approximate Distance From Pad 17 R to Fault Trace of Bow Ridge Fault Extended Along Dip to Surface, Line A In Figure 5	101 [330]
2. Distance from Fault Trace at Surface to Fault Trace at the Bedrock Surface (e.g., Distance *C* in Figure 3)	13 [43]
Total Separation Distance = Distance From Aging Pad 17R to the Fault Trace of the Bow Ridge Fault at the Bedrock Surface, Projected Vertically to Surface (e.g., = Distance *S* in Figure 2)	114 [373]
Pad 17 P	
1. Approximate Distance From Pad 17 P to Fault Trace of Bow Ridge Fault Extended Along Dip to Surface, Line B In Figure 5	136 [445]
2. Distance from Fault Trace at Surface to Fault Trace at the Bedrock Surface (e.g., Distance *C* in Figure 3)	13 [43]
Total Separation Distance = Distance From Aging Pad 17P to the Fault Trace of the Bow Ridge Fault at the Bedrock Surface, Projected Vertically to Surface (e.g., = Distance *S* in Figure 2)	149 [489]

NOTE: Locations of Lines A and B are identified in Figure 4.

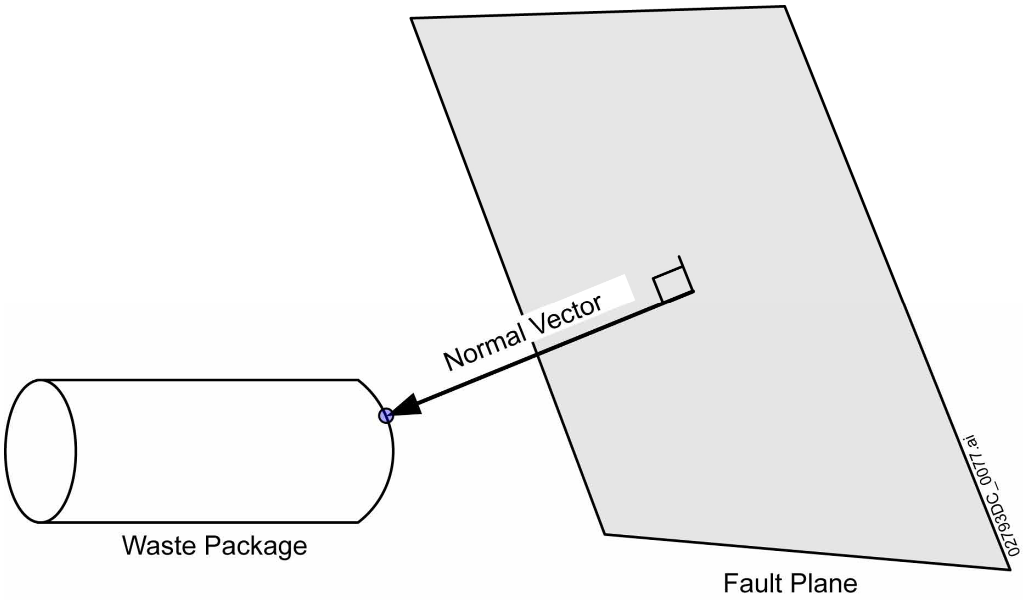

Figure 1. Schematic Diagram Showing Geometric Distance from the Edge of the Fault Damage Zone (Taken as a Plane) to Closest Point on Waste Package

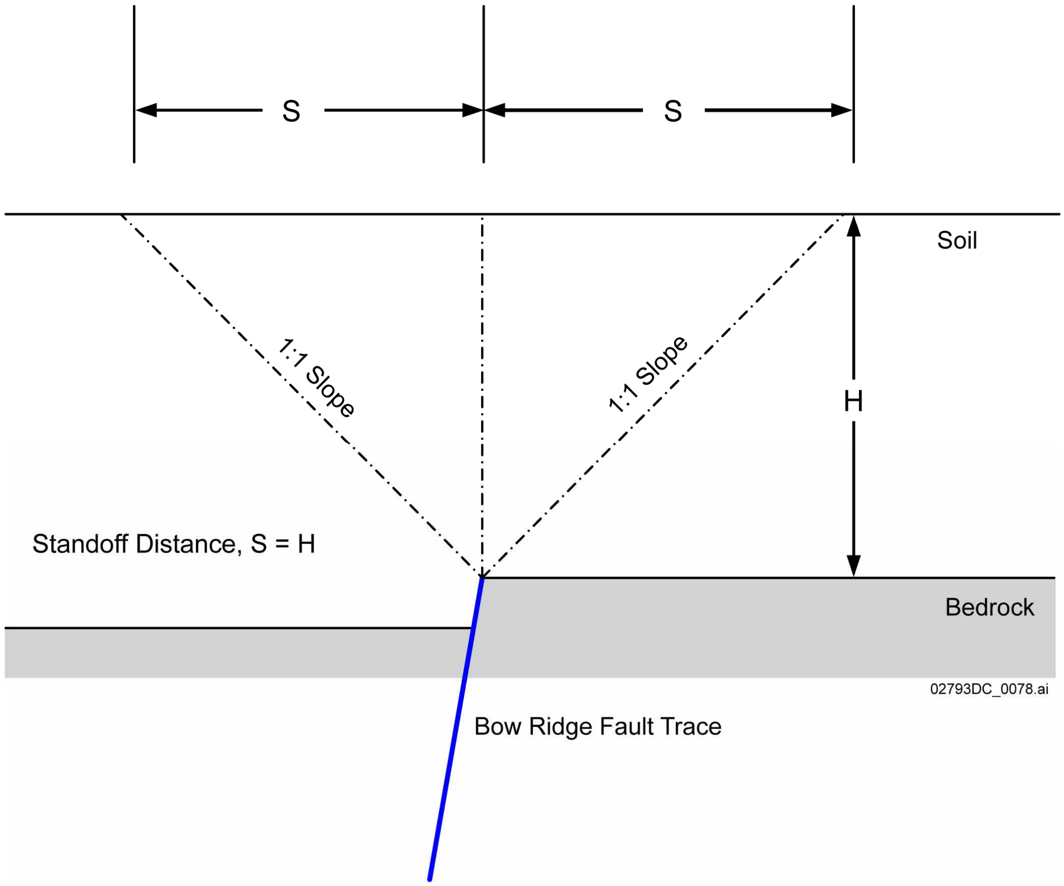

Figure 2. Schematic Diagram Showing Variables for ITS Surface Structure Standoff Distance Using 1:1 Approach

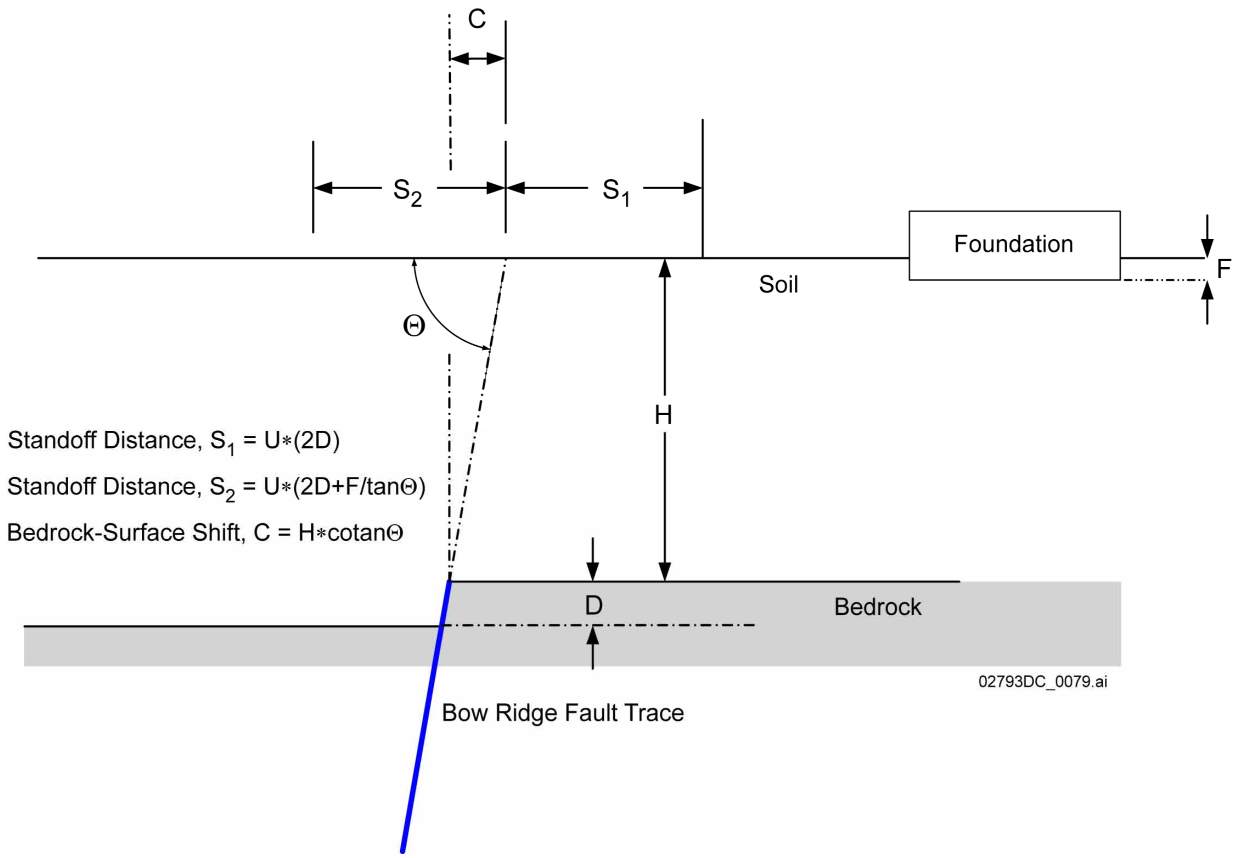

Figure 3. Schematic Diagram Showing Variables for Computing a Standoff Distance for a Surface Structure from a Holocene or Late Quaternary Fault Using Utah Geological Survey Approach

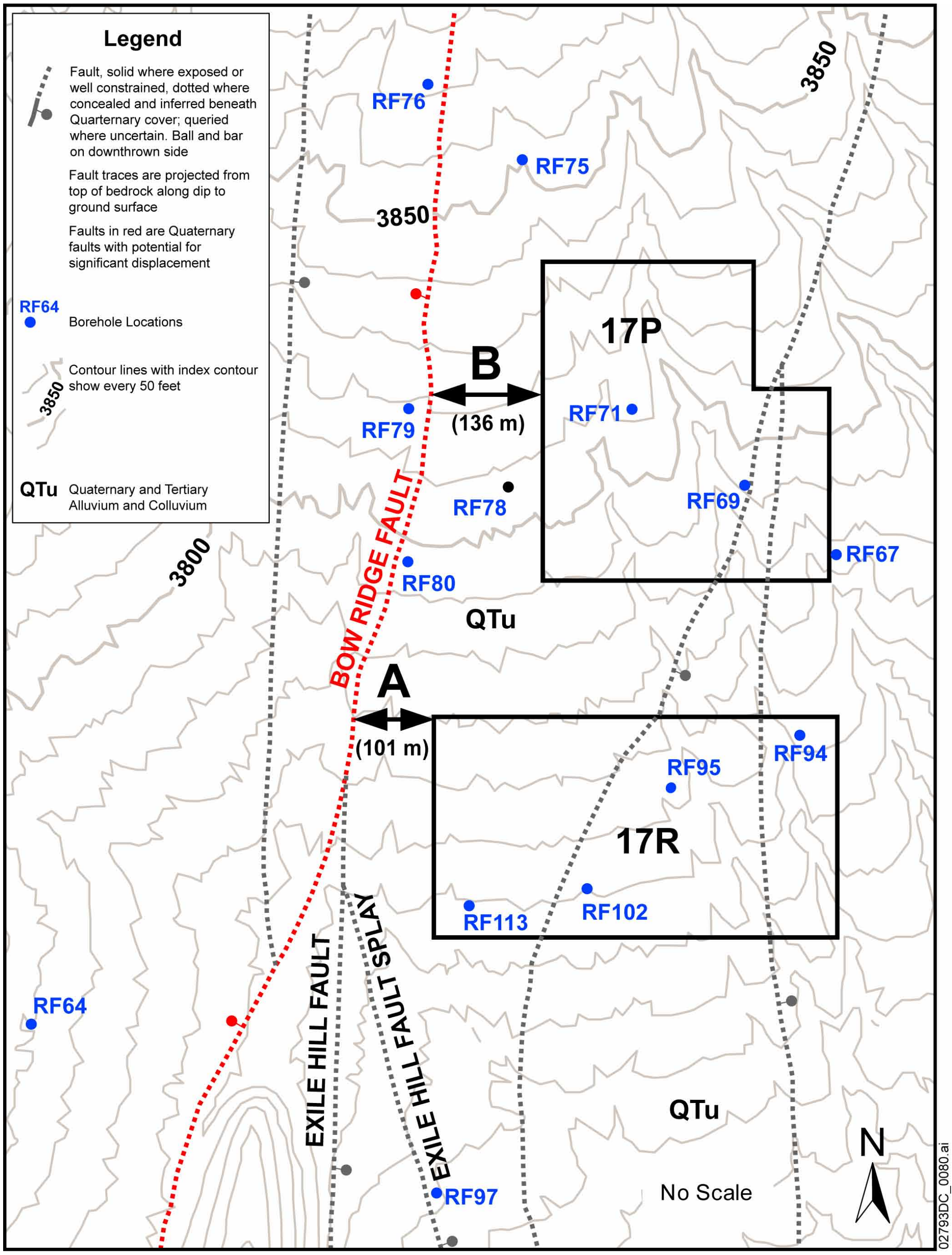

Figure 4. Illustration of Locations Where the Aging Pads are in Close Proximity to the Bow Ridge Fault

NOTE: The trace of the Bow Ridge Fault as shown has been projected from the top of bedrock to the surface along projection of the fault dip, and therefore, the distances A and B must be corrected to allow comparison to the 1:1 standoff distance criterion shown in Figure 2.

Faults without labels are unnamed. Faults in grey show no evidence of displacing Quaternary alluvial deposits, based on available geologic evidence.

Source: Modified from Figure 1 of Response to RAI 2.2.1.1.1-2-001. Trace of Bow Ridge Fault has been modified based on latest information.

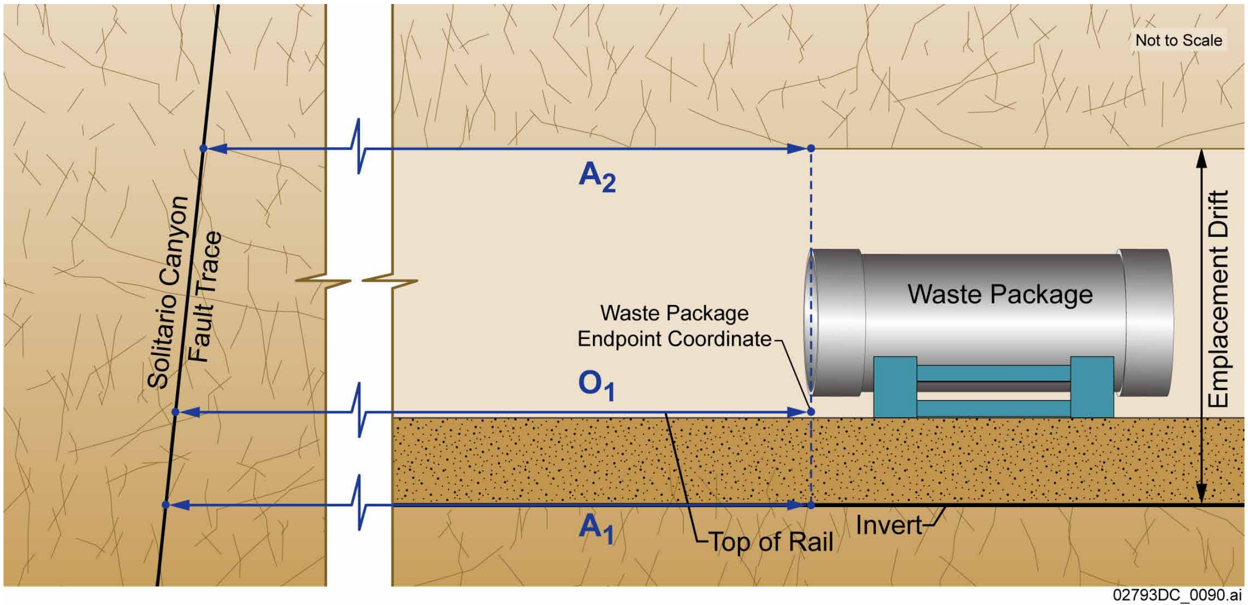

Figure 5. Revised Illustration of the 60 Meter Fault Standoff Distance of a Waste Package from a Quaternary Fault with Potential for Significant Displacement

NOTE: Figure supersedes Figure 1 of original response to RAI 2.2.1.1.1-2-003.

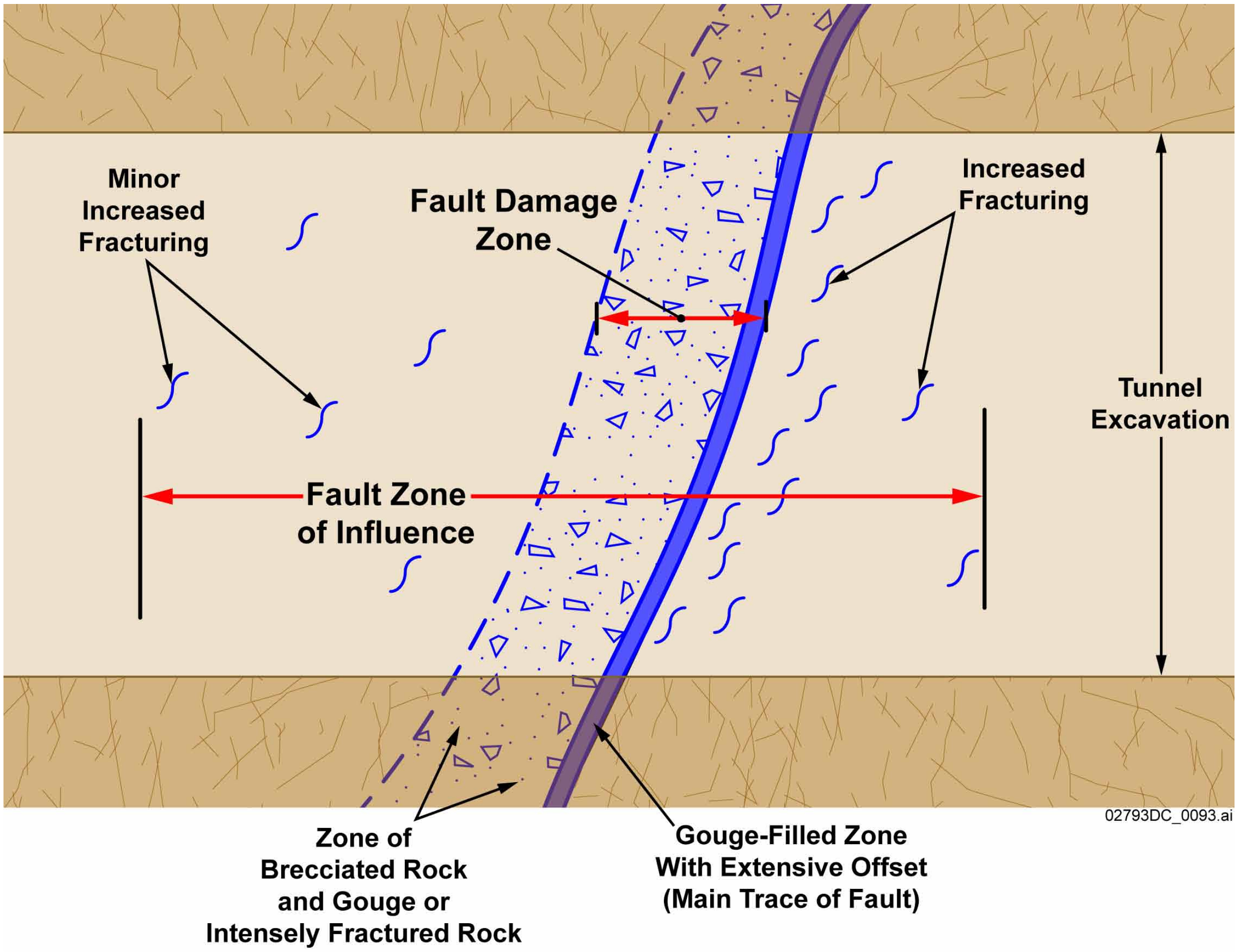

Figure 6. Idealized Cross-Section of a Tunnel Geology to Illustrate Difference Between a Fault Damage Zone and a Fault Zone of Influence